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TEACHING AND LEARNING MATHEMATICS WITH ROBOTICS IN MIDDLE-YEARS OF SCHOOLING

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Engaging and motivating students in mathematics lessons can be challenging. The traditional approach of chalk and talk can sometimes be problematic. The new generation of educational robotics has the potential to not only motivate students but also enable teachers to demonstrate concepts in mathematics by connecting concepts with the real world. Robotics hardware and the software are becoming increasing more user-friendly and as a consequence they can be blended in with classroom activities with greater ease. Using robotics in suitably designed activities promotes a constructivist learning environment and enables students to engage in higher order thinking through hands-on problem solving. Teamwork and collaborative learning are also enhanced through the use of this technology. This paper discusses a model for teaching concepts in mathematics in middle year classrooms. It will also highlight some of the benefits and challenges of using robotics in the learning environment.

Keyword: mathematics, robotics, constructivism

Introduction

In 2008 the Ministerial Council on Education, Employment, Training and Youth Affairs (MCEETYA), released the Melbourne Declaration on Educational Goals for Young Australians. This declaration outlines the direction for Australian schooling for the next 10 years. In its planned “commitment to action" middle years of schooling is considered to be critical. The declaration notes:

> The middle years are an important period of learning, in which knowledge of fundamental disciplines is developed, yet this is also a time when students are at the greatest risk of disengagement from learning. Student motivation and engagement in these years is critical, and can be influenced by tailoring approaches to teaching, with learning activities and learning environments that specifically consider the needs of middle years students. Focusing on student engagement and converting this into learning can have a significant impact on student outcomes.
>
> (MCEETYA, 2008, p. 12)

For learning to be effective, pedagogical strategies need to be developed which motivate and engage students. If engagement and motivation levels are high in classrooms, then this is more likely to impact positively on learning outcomes (McPhan, et. al., 2008). For this to occur learning activities have to be relevant and meaningful to students. This paper outlines how learning activities in robotics were designed and implemented in year eight mathematics lessons (First year of high school in Queensland schools). It also highlights some of the challenges faced by educators in integrating robotics activities.

Teaching Mathematics

Teaching concepts in mathematics should incorporate connectedness, structure and context, feedback, reflection and review, and intensity (Bell, 1993). Connectedness promotes the linking of existing and new concepts. Understanding the structure and context develops an understanding of the similarity between underlying structures in related topics. Feedback has to be instant and any false manifestations of ideas should be arrested early in the teaching process. Students should also have an opportunity to review and consolidate new ideas. Intensity promotes the learning - it enables learners to actively engage in range of problems and exercises of high quality.

Teaching mathematical concepts should also encompass the connectedness between physical, verbal, and symbolic representations (Payne & Rathmell, 1977). When concepts fail to make sense, learners stop learning. For this to occur, there has to be a seamless connection between the three representations.

The physical manifestation of the concept probably goes hand in hand with establishing connectedness. For instance, when we teach students about linear graphs, intercepts and gradients, how many actually understand what it means. How many times do we demonstrate the physical manifestation of $y = 5x + 3$? How does this equation connect with the real world? If students fail to see any relevance of the concept, then learning becomes very challenging. It also becomes boring and as a consequence they are likely to disengage from the task.

Mathematics draws on a range of abstract concepts. Sometimes establishing a link between the concept and the real world can be challenging as well. In such instances, understanding also becomes difficult. Hands-on engagement can some sometimes blur the boundary between the abstract and the real world. Sennett (2009) in his book the “Craftsman” points out that “all skills, even the most abstract, begin as bodily practices; second the power of understanding develops through the power of imagination. The first argument focuses on knowledge gained in the hand through touch and movement. The argument about imagination begins by exploring language through touch and movement.” (p. 10). He also believes that “understanding and expression are impaired” when “hand and head are separated” (p. 20). He points out that the craftsman “focuses on the inmate connection between hand and head. Every good craftsman conducts a dialogue between concrete practices and thinking; this dialogue evolves into sustaining habits, and these habits establish a rhythm between problem solving and problem finding” (p. 9).

Research in science also supports the importance of the hand and head connection. Scientists learn difficult by creating and manipulating models:

> Solving problems at the frontiers of science involves complex cognitive processes. In reasoning with models, part of the process occurs in the mind and part in the real-world manipulation of the model. The problem is not solved by the scientist alone, but by the scientist-model combination. This is a highly creative cognitive process.
>
> (Wiley-Blackwell, 2009, para. 3)

Using teaching aids in mathematics is not new concept. With advances in digital technologies some of the ideas anchored in constructivism can be translated in the teaching and learning of mathematics. Mathematical modeling with robotics can be used to introduce and extend mathematical concepts. It creates a meaningful opportunity for students to develop the head-hand connection of mathematics using robots.

LEGO® Robotics in Education

LEGO® MINDSTORMS® robots have been used in classrooms in a variety of ways since they were first introduced in the late 1990's. The latest generation of this technology – the LEGO® MINDSTORMS® NXT's are being increasing used in primary and secondary classrooms. These tools are user-friendly and promote the creation of a constructivist learning environment in a number of ways (Robyler, 2006):

a) Learning through social experiences, hands on engagement, and tasks connected to real world problems and issues (Dewy)
b) Discovery learning by interacting with the environment (Bruner)
c) Learning in the *Zone of Proximal Development* through scaffolded activities (Vygotsky).

The integration of this technology in constructivist environments has led to a number of positive outcomes. Research on the cognitive skills development associated with technology has established that use of robotics helps improve students' problem solving skills, critical thinking, collaboration, and communication (Barker & Ansorje, 2007). Robots enabled students to develop their knowledge in mathematics and science (Maud, 2009). Working with technology based processes of design also encouraged peer-tutoring, self-reflection and self-directed learning. Beisser and Gillespie (2003) compared undergraduate university students' work with RCX to that of kindergarten students, and found that both groups worked in a similar way – vocalising questions, collaboratively working on solutions and evaluating their work afterwards. However, students in early years using LEGO Mindstorms NXTs tended to engage more in the lessons insofar as these resembled play with a toy robot and its "adventures" through movement. By comparison students in the later years became engaged with the technological processes involved and acquired a deeper understanding of design and systems (Mauch, 2001).

The key objective of the research was to design, develop and implement a number of lessons in mathematics using LEGO® MINDSTORMS®

Research Design

A series of lessons were deigned and implemented for year 8 students in the 13-14 age group (N = 50). In Queensland (Australia), years 4 to 9 is generally defined as middle-years of schooling. Each lesson targeted either one or more concepts in mathematics. The lessons were designed to last for an hour with some additional questions for homework. The classes were a mixed group-with almost equal number of boys and girls. With the exception of the first and the last lesson, the structure of the other lessons were very similar. All lessons were developed using Blooms Taxonomy. Tasks within the lessons focused on the revised categories of the taxonomy (i.e Remembering, Understanding, Applying, Analysing, Evaluating, and Creating) (Forehand, 2005).

First lesson

The first lesson was designed to give students an overview of robotics. The primary objective of this lesson was to develop students understanding of how robots are built and programmed. In doing so, the importance of robots in human endeavourers was discussed. The lesson was divided into three parts – (1) basics of robotics, (2) building and (3) programming the robots. The components of LEGO® MINDSTORMS® toolset were discussed (eg. Input and output ports, sensors, servo motors, and so on). The functions of the buttons on the processor were also discussed.

In this lesson two "servo motors" were used build a robot. Step by step instructions were provided to build the robot. The emphasis was on connecting the pieces (eg. connector pegs, axel, wheels) correctly. Programming involved an exploration of the MINDSTORMS®NXT software interface (Figure 1).

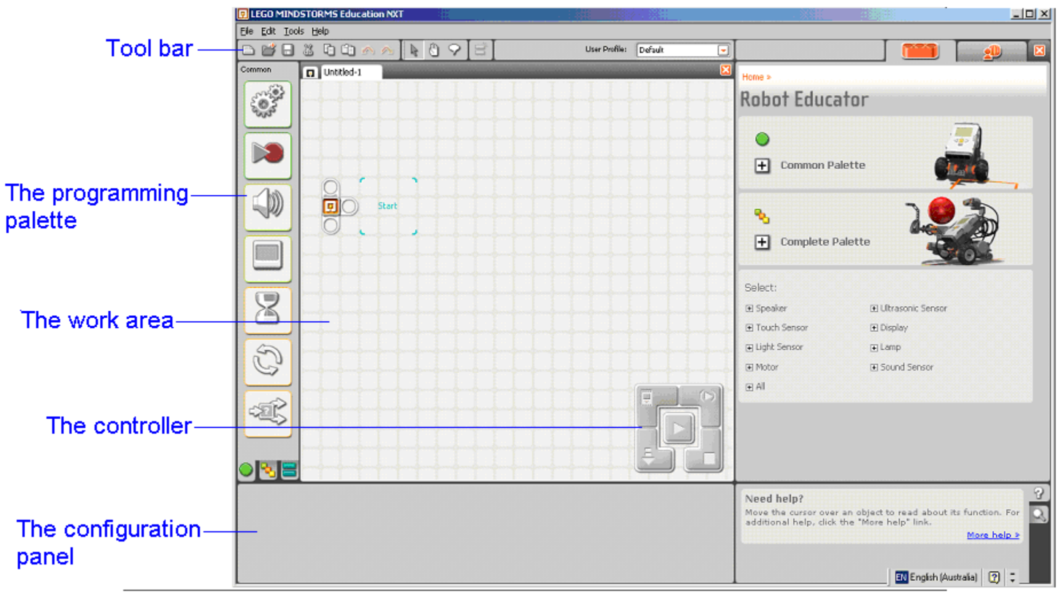


Figure 1 – Features of the MINDSTORMS®NXT working area

The key features of the MINDSTORMS®NXT working area were identified. The purposes of the – "tool bar, programming palette icons, work area and the controller" were explained. The importance of the configuration panel in programming was made explicit. Students had to understand how the "port, direction, steering, power, duration and next action" impacted on the programming sequence of the robot (see Figure 2). Simple instructions were critical in establishing how a simple robot program was created and downloaded to the processor (Figure 2).

To program the robot:

a) Drag the MOVE icon to the START position (left click on the mouse button for this action)

b) Choose Port A (make sure that the other ports are unticked)

c) Change the duration to 10 rotations

d) Use the USB cable and connect the robot to the computer. Use the controller and download the program to the NXT processor. (Make sure that the processor is turned on. When program transfer has occurred you will hear a noise – it should take a few seconds).

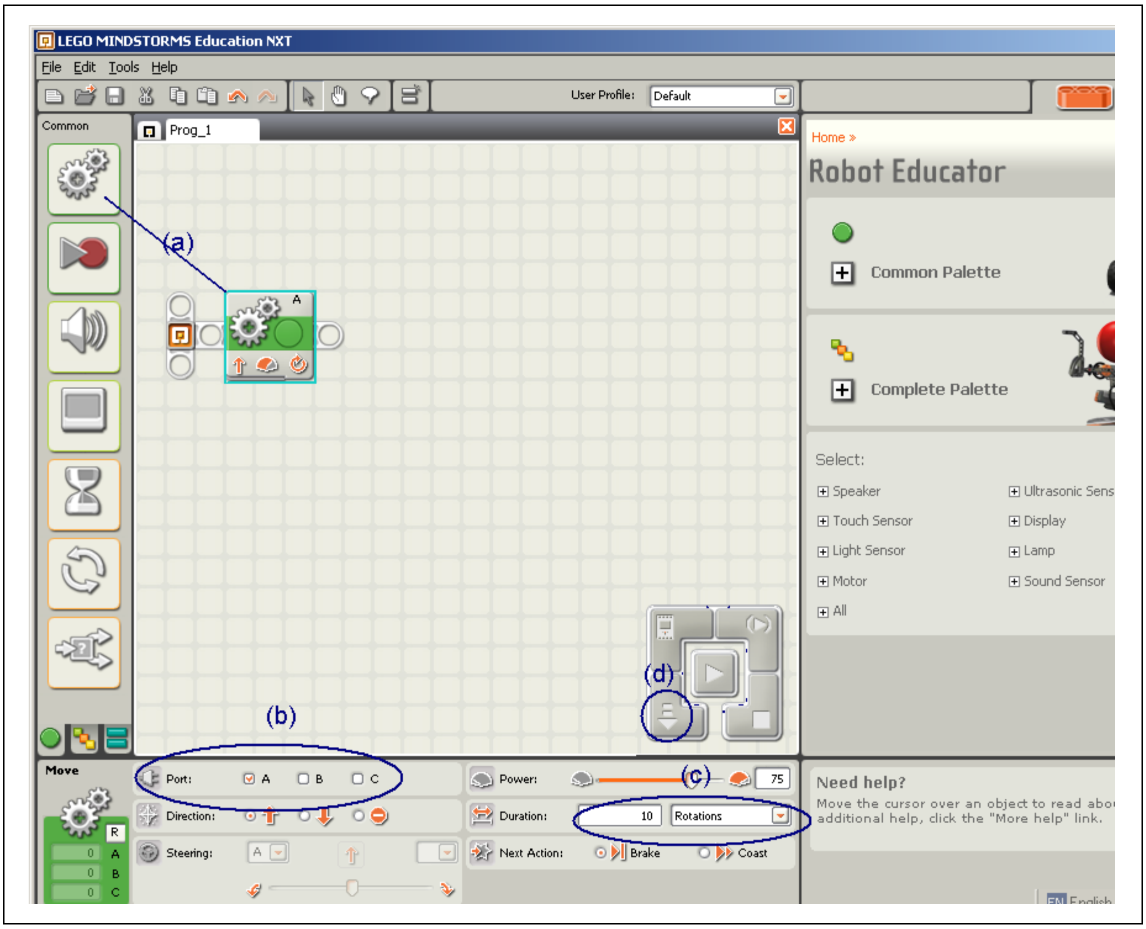


Figure 2: Programming a basic robot

Students were also given opportunities to change variables on the control panel, download the program to the processor and run the robot. The first lesson established the basics of building and programming. Subsequent lessons shifted the focusing to connecting building and programming with mathematics.

The layout of lessons

Once students were familiar with the basics of building and programming robots, the lessons that followed had a consistent structure. In a typical lesson students were allocated 5 to 10 minutes to students to build their robots. Each lesson had a catchy title (eg. “The faster robot”). The key concepts of the lesson were discussed (e.g. graphing, predictions, variables). The tasks within the lesson were closely aligned with Blooms Taxonomy (revised). There was a progressive build-up of the thinking required to complete the tasks as the lesson progressed. The lessons were divided into three parts:

a) Investigating

In this part students would program the robot, take some measurements, apply their in class knowledge to tasks and do something with the data gathered (eg. tabulating and graphing data). Generally the thinking skills for these tasks were predominantly associated with remembering/recall, understanding, and application of their knowledge. Table 1 gives examples of the tasks completed in this part of the lesson.

Table 1: Applying Blooms Taxonomy in the investigation part of the lesson

<table>
<tr><th>Blooms Category</th><th>Definition[#]</th><th>Sample task</th></tr>
<tr><td>Understanding</td><td>Constructing meaning from oral, written, and graphic messages through interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining.</td><td>1. Set the power level to 50
2. Program your robot to travel for 1 second

3. Download the problem and run the robot from the start line.</td></tr>
<tr><td>Applying</td><td>Carrying out or using a procedure through executing, or implementing.</td><td>4. Measure the distance travelled in centimetres.
5. Record your measurement in the table below:<table><tr><td>Power level</td><td colspan="2"></td><td colspan="3">50</td></tr><tr><td>t(s)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr><tr><td>d(cm)</td><td></td><td></td><td></td><td></td><td></td></tr></table>
6. Repeat steps 2-5 by programming your robot to travel for 2, 3, 4, and 5 seconds.
7. Plot this data on a graph.</td></tr>
</table>

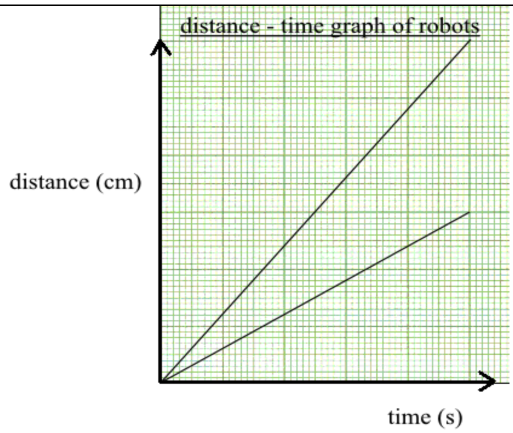
[#]Anderson & Krathwohl, 2001, pp. 67

As shown in the table above, in this part students are programming the robot. They are "constructing meaning" from "written messages" to achieve this. Using these messages, students create and download a program which is executed by the robot. The distances travelled by the robot is measured, recorded in table and then graphed. There is a connection between the robots motion, the data gathered and the graph which is plotted from it.

b) Explaining and predicting

In this part of the activity students interpreted their outputs (eg. graphs). In terms of Blooms Taxomy, the focus was on analyzing their results. For instance in one of the activities, two graphs were plotted which showed the motion of two robots. In order to interpret the graphs, students were given a series of questions to guide their thinking (Table 2).

Table 2: Applying Blooms Taxonomy in the explaining and predicting part of the lesson

Blooms Category	Definition[#]	Sample task
Analysing	Breaking material into constituent parts, determining how the parts relate to one another and to an overall structure or purpose through differentiating, organizing, and attributing.	 1. What are the variables in this activity? 2. What is the (i) dependent and (ii) independent variable? 3. Which variables are kept constant (do not change)? 4. What information can you gather from the two graphs? 5. If there was a race between the two robots, which robot would win and why?

[#]Anderson & Krathwohl, 2001, pp. 67

One of the key aspects of analyzing is to break "materials into constituent parts" and determine "how the parts relate to one another" (Anderson & Krathwohl, 2001, p. 67). Here (Table 2), looking at parts of the graph and explaining the similarities and differences between them is critical to understanding why they are drawn. The activity presents an opportunity to demonstrate connectedness between the concept of variables and gradient with a real world example. The last question in the example in Table 2 lends itself to extending the students' thinking. "If there was a race between the two robots, which robot would win and why?" In this question the importance of the gradient of the lines play an important role in making their prediction.

c) Testing

In the final step (testing) students evaluate their predictions based on the analysis that was carried out earlier. Two categories of Blooms Taxonomy – evaluating and creating form the basis of the task in this part of the lesson.

Table 3: Applying Blooms Taxonomy in the testing part of the lesson

Blooms Category	Definition[#]	Sample task
Evaluating	Making judgments based on criteria and standards through checking and critiquing.	Now, test your prediction by racing the two robots (see Table 2).
Creating	Putting elements together to form a coherent or functional whole; reorganizing elements into a new pattern or structure through generating, planning, or producing.	Without redesigning the robot or changing its settings, how can the slower robot win? Give reasons.

[#]Anderson & Krathwohl, 2001, pp. 68

At this stage of the lesson, students test their prediction. They get an opportunity to understand that the robot with a line graph that has a higher gradient (see Table 2) wins the race. They get an opportunity to make a judgment on the basis of the data that is in front of them. On the basis of this information, they put forward a hypothesis with reason "Without redesigning the robot or changing its settings, how can the slower robot win? Give reasons." This represents the last step in the thinking process – here they are bringing together all the knowledge gained in the activity earlier to demonstrate their understanding.

Reflections

As an educator with many years of teaching experience in mathematics, I found that the learning activities in this study excited and enthused students immensely. Instead of the usual scenario of "here is an example of how you draw a graph and now do Exercise 3c, Numbers 1a, 4d, e, f and 8" – students in this study were actually excited about studying mathematics.

Concepts in mathematics were demonstrated to have a connection with the real world (Bell, 1993). For instance, graphs drawn in mathematics actually meant something. A co-ordinate had an x and y value for a reason. Such connections gave numerous opportunities for students to experience the significance of physical, verbal, and symbolic representations in mathematics (Payne & Rathmell, 1977).

The manipulation of robots facilitated the connection between head and hand and enhanced the quality of the cognitive processes involved in understanding concepts in mathematics (Sennett, 2009; Wiley-Blackwell, 2009). This was evident in the number of students who were able to complete the most of set tasks in the given time. The testing stage of the lessons often challenged the students, but this was to be expected. It created new opportunities to solve given problems and find new ones (Sennett, 2009).

The use of robots presented a real opportunity for students to engage in a constructivist-learning environment. There was a high level of interaction between students. They were not only learning by verbalising and discussing the tasks, they were also learning by observing how other students were responding to the tasks. The hands-on engagement kept them focussed. There was no evidence of students sitting idle during the lessons. By appropriately scaffolding the activity, students were guided from one step to another with great ease. There were also numerous opportunities for discovery learning.

Conclusions

The user-friendly nature of the new generation of robots presents new opportunities for teachers to revisit their pedagogical approaches to teaching mathematics. Through innovative learning activities, robotics can show the connections between mathematics and the real world. More importantly it captures childrens' attention and interest and as a consequence they the enjoy experience. Activities with these qualities are more likely to deliver desirable learning outcomes.

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